INNOVATION-ADJUSTED PRICE INDEXES FOR PHARMACEUTICALS

Sangin Park

Department of Economics
SUNY at Stony Brook
Stony Brook, NY 11794-4384
Tel: 631-632-7559
Email: sanpark@notes.cc.sunysb.edu

This Draft: September 2000

Pharmaceuticals are a special case of goods with some unobservable quality prior to consumption, which is called an "experience characteristic". Consumers learn these experience characteristics from both consumption experience and advertising exposure. Based on the Bayesian learning process of experience characteristics and the characteristics approach to demand functions, this paper proposes *innovation-adjusted* price indexes for pharmaceuticals. This structural approach not only resolves the quality adjustment of new molecules but also avoids arbitrary assumptions on the link-in of generic drugs to the originator branded drug. The suggested price indexes are applied to the data for antidepressant drugs during the years 1980-1995. This paper has found: (i) the key source of innovations was the entry of new products, but the effects of learning about experience characteristics were also significant; and (ii) the average annual growth rate of the focal price index is almost –9.5%, which suggests that the existing price indexes for pharmaceuticals may seriously overstate the rate of inflation in a rapidly growing market with the entry of innovative products.

Keywords: innovation-adjusted price indexes; experience characteristic; informational product differentiation; link-in problem; learning; antidepressant drugs.

JEL Classification: C43; L65.

I. Introduction

CURRENTLY PRICE INDEXES FOR PHARMACEUTICALS are a major issue of the U.S. health care reform. There are several reasons that the construction of price indexes is a challenging task in the case of pharmaceuticals. In the pharmaceutical industry, as in many other important industries, technological progress takes the form of new products: there are usually a significant number of new molecules and the generic entry after patent expiration. In general, it is not easy to construct price indexes which truthfully reflect changes in consumer welfare resulting from the entry of new products (see Hausman (1997)). The conventional Laspeyres price index fails to capture the entry of new products while the conventional Paasche price index requires measuring reservation prices of new products in the base period. Measuring the base-period's reservation prices of new products is a difficult task. One possibility is to predict the reservation prices based on the estimates of hedonic price indexes (see Berndt, Griliches and Rappaport (1995); and Berndt, Cockburn and Griliches (1996)).[1] In an imperfect competition, however, hedonic price indexes do not fully reflect the quality adjustment of new products (see Trajtenberg (1990)).

On top of this general problem, in the case of pharmaceuticals, the entry of generics makes things more complicated. As noted in Griliches and Cockburn (1994), the estimates of hedonic price indexes cannot be used as a prediction of the reservation price of a generic drug since a generic drug is 'therapeutically equivalent' to the originator branded drug and thus has the same observable characteristics even with a substantially lower price than its originator branded drug.[2] Hence how to link in generic drugs to their originator branded drug is an important and

[1] An alternative approach is based on a constant-elasticity-of-substitution utility function for variety of differentiated products (see Feenstra (1996)). This approach takes the reservation price as infinite, and calculates a finite consumer surplus from the introduction of a new variety.

[2] Food and Drug Administration requires generic drugs to have the exact same active ingredients in same form and concentration of the originator branded drug.

challenging issue.[3] Until recently the Bureau of Labor Statistics (BLS) has calculated the Producer Price Indexes (PPIs), treating generic drugs as entirely distinct and non-substitutable products. The Food and Drug Administration (FDA), on the other hand, argues the other extreme: "a pill, is a pill, is a pill." In this case, the relevant price for a molecule will be the weighted average price of all generic drugs and the branded drug within the molecule. Based on the observation that not all consumers will switch to a cheaper generic version of a drug despite a significant price differential between the generic and the originator branded drug, Griliches and Cockburn (1994) tackled the link-in issue, assuming a linear utility framework and a uniform distribution function on consumers' different tastes for "brandedness". They also noticed a diffusion problem: without much change in the price differential, the share of generics has significantly increased between six months and a year after generic entry. Combining the assumption of consumers' tastes for brandedness with the observation of the diffusion problem, they calculated the base-month's reservation price of a generic drug as the average six-month-later price of the generic drug and the originator branded drug.

In this paper, we propose *innovation-adjusted* price indexes for pharmaceuticals, based on informational product differentiation and characteristics approach to demand functions. Informational product differentiation between generic drugs and the originator branded drug has been recognized in the literature (see Schmalensee (1982)). Although generics are therapeutically equivalent to the originator branded drug, there is some possible difference in inactive ingredients, shelf life, etc., which can affect the quality of the generics. In general, pharmaceuticals, branded or generic drugs, have some unobservable quality prior to consumption, which is called an "experience characteristic" by Currie and Park (2000). The consumer (the physician-patient pair, with the patient making the choice upon the advice of his/her physician)[4]

[3] Griliches and Cockburn (1994) found significant differences in price indexes for anti-infective drugs across different assumptions on the link-in.

[4] A moral hazard problem is not directly considered in this paper. However, we discuss the implications of the moral hazard problem at the end of section IV.

will learn the experience characteristics of drugs from both consumption experience and advertising exposure. The branded drug may have an advantage over generics in both consumption experience and advertising, and thus rational consumer behavior can give pioneering brands advantages. As generics accumulate more sales, the informational advantage of the branded drug will diminish. Hence, in the context of the informational product differentiation, the diffusion problem in Griliches and Cockburn (1994) can be understood as a learning process.

In the paper, the consumer's learning of experience characteristics will be modeled as a Bayesian learning process. Treating the link-in and the diffusion problem in a context of learning and informational product differentiation, we avoid arbitrary assumptions on the link-in of generic drugs to the branded drug. In addition, the characteristics approach to demand functions enables us to derive an expenditure function and thus to calculate two ideal price indexes as well as those suggested in Trajtenberg (1990). These ideal price indexes are called *innovation-adjusted price indexes* in the paper. These innovation-adjusted price indexes capture the value of innovations as the benefits of the latest choice set rather than the previous ones. Therefore, the innovation-adjusted price indexes truthfully quantify changes in consumer welfare resulting from the entry of new products as well as consumers' learning about experience characteristics in the framework of informational product differentiation and characteristics approach to demand functions.

The suggested innovation-adjusted price indexes will be applied to the data for antidepressant drugs during the years 1980-1995. During these years, the market for antidepressants experienced 'exceptional and remarkable' innovations in terms of entry of new products (both new molecules and generics). In 1980 and 1981, the second-generation of antidepressant drugs called tricyclic antidepressants (TCAs) entered the market. Until the year 1979, the first generation of TCAs, most of which were introduced in 1960's, had dominated the market. Beginning in 1986, there was an active entry of generic drugs induced by the passage of the 1984 Waxman-Hatch Act. Most importantly, the breakthrough drug, Prozac, was introduced

to the market in 1988, and subsequently three more drugs in the same therapeutic subclass entered by the year 1995. The calculated innovation-adjusted price indexes confirm the occurrence of exceptional and remarkable innovations during these years: the Average Annual Growth Rate (AAGR) of our focal price index is almost –9.5%. Although the entry of new products was the key source of innovations, the effects of learning about experience characteristics were also significant. The comparison of our innovation-adjusted price indexes with the other existing indexes discussed in Berndt, Cockburn and Griliches (1996) suggests that the existing price indexes for pharmaceuticals may seriously overstate the rate of inflation in a rapidly growing market with the entry of innovative products.

While the topic of this paper is on pharmaceuticals, the problem discussed in the paper is of wider importance. A novelty of this paper is that the suggested innovation-adjusted price indexes enable us to quantify the effects of consumers' learning when the products in question have some unobservable quality prior to consumption. The significance of the effects of consumers' learning in the case of antidepressant drugs indicates that the correct formula for price indexes cannot be determined solely by the principle of commodity substitution. A similar problem can be found in the issue of outlet substitution in consumer price index estimation. The outlet substitution problem induced by the rapid growth of low-price outlets was recognized by Reinsdorf (1993) and is now considered as one of the most important issues in the research on price index measurement (see Berndt (1999)).

The remainder of the paper is organized as follows. Section II will describe the model for consumers' decision-making and the learning process of experience characteristics. Section III will construct the innovation-adjusted price indexes based on our structural approach. Section IV will calculate these price indexes for antidepressant drugs during the years 1980-1995, which will be compared with other indexes discussed in Berndt, Cockburn, and Griliches (1996). Section V will conclude the paper.

II. Informational Product Differentiation and Learning Process

Pharmaceuticals in general have some unobservable quality prior to consumption. Currie and Park (2000) called this an experience characteristic.[5] Let μ_{ijt} denote consumer *i*'s utility of product *j*'s experience characteristic in period *t*. A "product" means a branded version or a generic version of a drug (or molecule) in this paper. Assume that the consumer's experience μ_{ijt} is distributed as: $\mu_{ijt} = \delta_j + \nu_{ijt}$, where δ_j is the mean level of experience characteristic, and ν_{ijt} is consumer *i*'s idiosyncratic experience in period *t* and has the zero mean conditioned on his/her information set, I_{it}. We treat the mean level of experience characteristic δ_j as a random variable and thus consider the possibility that the consumers can randomly get "lemons" or "windfalls". The consumer's idiosyncratic experience ν_{ijt} includes unanticipated patient-drug specific interactions.

The consumer (the physician-patient pair, with the patient making the choice upon the advice of his/her physician) learns and anticipates (the mean level of) an experience characteristic based on the patient's consumption experience, the physician's prescription experience and advertising exposure. We take into account that the physicians can pool each other's information through journal articles, professional conferences, and informal communications with each other. Hence we assume that all the consumers in a period receive the same experience signal for a product, say μ_{jt}. Let ν_{jt} denote a measurement error in the process of information pooling. Then the consumer's experience in period *t* can be rewritten as:

$$\mu_{jt} = \delta_j + \nu_{jt}. \quad (1)$$

[5] This section borrows heavily from Currie and Park (2000).

We also consider that advertising messages may provide information about (the mean level of) an experience characteristic. Assuming the information pooling process again, the advertising signal of product j that consumer i will receive in period t, say A_{jt}, can be expressed as:

$$(2) \qquad A_{jt} = A_j + \xi_{jt},$$

where A_j is the mean level of the advertising signal, and ξ_{jt} is a measurement error. Like the mean level of experience characteristic δ_j, we will treat the mean level of advertising A_j as a random variable as well. Then the positive correlation between δ_j and A_j will indicate that the advertising signal provides indirect information on δ_j.

We model the consumer's learning of experience characteristics via consumption experience and advertising experience as a Bayesian learning process. To facilitate the construction of Bayesian learning process, we make the following two assumptions. First, suppose that the measurements errors, both v_{jt} and ξ_{jt} in (1) and (2), are *i.i.d.* normal random variables with zero means and variances of σ_v^2 and σ_ξ^2, respectively. In other words, on average, the consumption experience μ_{jt} and the advertising experience A_{jt} indicate the product's mean level of experience characteristic δ_j and the product's mean level of advertising experience A_j, respectively.[6] Hence we assume:

$$(3) \qquad \begin{bmatrix} \mu_{jt} \\ A_{jt} \end{bmatrix} \sim i.i.d.\ N\left(\begin{bmatrix} \delta_j \\ A_j \end{bmatrix}, \begin{bmatrix} \sigma_v^2 & 0 \\ 0 & \sigma_\xi^2 \end{bmatrix} \right).$$

[6] Consumers may also associate A_j with a particular image of the product. Currie and Park (2000), however, found no significant image effect in the case of antidepressant drugs.

Second, suppose that all consumers have the same prior distribution of $(\delta_j, A_j)'$ for each product j as follows:

$$(4) \qquad \begin{bmatrix} \delta_j \\ A_j \end{bmatrix} \sim i.i.d.\, N\left(\begin{bmatrix} m_{j0}^{\delta} \\ m_{j0}^{A} \end{bmatrix}, \Sigma_0\right),$$

where Σ_0 is the initial covariance matrix of $(\delta_j, A_j)'$. Then using the theory of conjugate distributions, the posterior distribution of $(\delta_j, A_j)'$ is given by a normal distribution with a mean of $(m_{jt}^{\delta}, m_{jt}^{A})'$ and a covariance matrix Σ_{jt} as follows:

$$(5) \qquad \begin{bmatrix} m_{jt}^{\delta} \\ m_{jt}^{A} \end{bmatrix} = \Sigma_{jt}\left(\Sigma_0^{-1}\begin{bmatrix} m_{j0}^{\delta} \\ m_{j0}^{A} \end{bmatrix} + \begin{bmatrix} (t_j - 1)/\sigma_v^2 & 0 \\ 0 & t_j/\sigma_\xi^2 \end{bmatrix}\bar{z}_{jt}\right),$$

where

$$\Sigma_{jt} = \left(\Sigma_0^{-1} + \begin{bmatrix} (t_j - 1)/\sigma_v^2 & 0 \\ 0 & t_j/\sigma_\xi^2 \end{bmatrix}\right)^{-1}, \text{ and}$$

$$\bar{z}_{jt} = \begin{bmatrix} \sum_{s=t_{j0}}^{t-1} \mu_{js}/(t_j - 1) \\ \sum_{s=t_{j0}}^{t} A_{js}/t_j \end{bmatrix},$$

where t_{j0} denotes the year when product j was introduced, and t_j indicates the years since the introduction of product j, i.e., $t_j = t - t_{j0} + 1$. Hereafter we simply call m_{jt}^{δ} experience characteristic of product j in period t. The posterior variance Σ_{jt} indicates that the signal noises, v_{jt} and ξ_{jt}, will phase out as time passes. Note that σ_v^2 and σ_ξ^2 are assumed known to consumers in the conjugate distributions theory although this assumption can be avoided at a cost of complexity of an updating rule. In empirical studies on experience goods, the consumption experience μ_{jt} is

usually assumed to be proportional to the sales of a product, say q_{jt}: $\mu_{jt} = \theta_4 q_{jt}$ (for example, Erdem and Keane (1976); Ackerberg (1997); Currie and Park (2000)). This is a restrictive but necessary assumption when there is no available data on consumption experiences.

In general, pharmaceuticals are differentiated by observable product characteristics as well as experience characteristics. Taking account of product differentiation, we use the nest logistic assumptions in Cardell (1997) to specify the consumer's utility level for a pharmaceutical. Let p_{jt} denote the price, and X_{jt} denote a vector of product characteristics. Let ζ_{igt}, ς_{imt}, and ε_{ijt} denote consumer i's idiosyncratic taste for therapeutic subclass g, idiosyncratic taste for molecule m, and idiosyncratic taste for product j, respectively. Then, in period t, the consumer's expected (prior-to-consumption) utility for product j of molecule m in therapeutic subclass g is given by:

$$(6) \qquad E[U_{ijt} \mid I_{it}] = \theta_1 - \theta_2 p_{jt} + X_{jt}\theta_3 + m_{jt}^{\delta} + \zeta_{igt} + (1-\sigma_g)\varsigma_{imt} + (1-\sigma_g)(1-\sigma_m)\varepsilon_{ijt},$$

where σ_m and σ_g are parameters which have values greater than or equal to zero and less than one. If σ_m (σ_g) has a value closer to one, then the products (molecules) within a molecule (subclass) are considered more homogenous. The employed nested logit assumptions posit that consumers first choose a therapeutic subclass or the outside alternative (say, $j = 0$), then a molecule within the chosen subclass, and then a branded version or a generic version of the chosen molecule. Choosing the outside alternative means either no treatment at all or non-drug treatments such as psychotheraphy.

The nested logistic assumptions in Cardell (1997) lead to a closed form of market share function for each product as follows:

$$(7) \qquad S_{jt}(\theta_0) = \frac{e^{\rho_{jt}/(1-\sigma_g)(1-\sigma_m)} E_{mt}^{-\sigma_m} D_{gt}^{-\sigma_g}}{1+\sum_g D_{gt}^{1-\sigma_g}},$$

where $\theta_0' = (\theta_1, \theta_2\theta_3', \theta_4, \sigma_m, \sigma_g, m_{j0}^{\delta}, m_{j0}^{A}, \Sigma_0)$, $\rho_{jt} = \theta_1 - \theta_2 p_{jt} + X_{jt}\theta_3 + m_{jt}^{\delta}$, $E_{mt} = \sum_{j \in m} e^{\rho_{jt}/(1-\sigma_g)(1-\sigma_m)}$, and $D_{gt} = \sum_{m \in g} E^{1-\sigma_m}$. An empirical study with market-level data usually encounters an unobservable (to economists) product characteristic, which can be treated as an error term in an estimation procedure of a logistic demand function for a differentiated product (see, for example, Berry, Levinsohn and Pakes (1999)). In the case of pharmaceuticals, an unobservable characteristic may represent the experience characteristic since all the other characteristics such as side effects are usually available information (see, for example, Stern (1996)). In our model, however, the (expected) experience characteristics of products are calculated using a Bayesian learning process. Hence we will explicitly consider the measurement errors in the data of reported market shares (or sales) and apply a non-linear least squares estimation procedure to obtain a consistent and asymptotically normal estimator of θ_0 in the demand function of (7) and the learning process of (5). Table 1 reports results of this estimation applied to the antidepressant drugs for the years 1980-1995. There are usually two types of advertisement in the case of pharmaceuticals: printed ads in medical journals and detailing (face-to-face visits to doctors by representatives of pharmaceutical companies). The hypothesis tests in Currie and Park (2000) have found that: (i) the Selective Serotonin Reuptake Inhibitor (SSRI) subclass has a different parameter value of consumption experience, θ_4; and (ii) the initial priors of δ_j and A_j (i.e., $m_{j0}^{\delta}, m_{j0}^{A}$) can be set to be zero. For the detailed discussion of the estimation procedure and the estimation and hypothesis testing results, refer to Currie and Park (2000).

III. Innovation-Adjusted Price Indexes

In this section, we will construct innovation-adjusted price indexes, based on the characteristics approach to demand functions in section II. These innovation-adjusted price indexes will capture the value of innovations as the benefits of the latest choice set rather than the previous ones. In general, innovations result from quality improvement or price reduction of existing products, the introduction of new products, or consumers' learning about experience characteristics.

Using the nested logistic assumptions applied to the derivation of the market share function in (7), we obtain the consumer's indirect utility function (or consumer surplus function) as follows:

$$(8) \qquad \gamma_t = y_t + \ln[\sum\nolimits_g D_{gt}^{1-\sigma_g}]/\theta_2 ,$$

where the income, y_t, and prices are real in the sense that they are deflated by the price index for the outside alternative (a composite outside good other than those J products under consideration). In the calculation of section IV, the Consumer Price Index (CPI) is used as the price index for the outside alternative. Hence the price indexes suggested in this section indicate the change of innovation-adjusted *real* prices and will be called *real* price indexes. For the comparison with other available indexes, the real price indexes are multiplied by the CPI and converted into (nominal) price indexes. The indirect utility function in (8) is additively separable in y_t since income effects are assumed away in the nested logistic model. Inverting the indirect utility function in (8), we can derive an expenditure function as follows:

$$(9) \qquad e(\gamma_t, p_t, X_t, m_t^{\delta}) = \gamma_t - \ln[\sum\nolimits_g D_{gt}^{1-\sigma_g}]/\theta_2 \equiv \gamma_t - W(p_t, X_t, m_t^{\delta}) .$$

The expenditure function in (9) assigns the minimum expenditure required by the consumer to achieve the utility level γ_t given the choice set characterized by prices, product characteristics and experience characteristics, (p_t, X_t, m_t^δ).

Then "ideal" price indexes can be calculated as either

$$I^0 = \frac{e(\gamma_{t-1}, p_t, X_t, m_t^\delta)}{e(\gamma_{t-1}, p_{t-1}, X_{t-1}, m_{t-1}^\delta)} = \frac{\gamma_{t-1} - W(p_t, X_t, m_t^\delta)}{\gamma_{t-1} - W(p_{t-1}, X_{t-1}, m_{t-1}^\delta)}$$

(10) or

$$I^1 = \frac{e(\gamma_t, p_t, X_t, m_t^\delta)}{e(\gamma_t, p_{t-1}, X_{t-1}, m_{t-1}^\delta)} = \frac{\gamma_t - W(p_t, X_t, m_t^\delta)}{\gamma_t - W(p_{t-1}, X_{t-1}, m_{t-1}^\delta)},$$

depending on the reference utility level.[7] Note that I^0 is not a feasible index when innovations are drastic. Also note that $I^1 \geq I^0$.

We can also construct the price indexes suggested in Trajtenberg (1990), which do not depend on the reference utility level. Since the expenditure function is additively separable in γ_t, the compensating and equivalent variations are the same. Hence we have:

$$e(\gamma, p_{t-1}, X_{t-1}, m_{t-1}^\delta) - e(\gamma, p_t, X_t, m_t^\delta) = W(p_t, X_t, m_t^\delta) - W(p_{t-1}, X_{t-1}, m_{t-1}^\delta) \equiv \Delta W_t$$

Let ϕ_t be the hypothetical average price reduction that would have had the same welfare consequences as the innovations that actually took place. Then

(11) $$\Delta W_t = W((1-\phi_t)p_{t-1}, X_{t-1}, m_{t-1}^\delta) - W(p_{t-1}, X_{t-1}, m_{t-1}^\delta).$$

Hence a price index can be computed simply as $J^0 = 1 - \phi_t$. This price index, like I^0, is not feasible when innovations are drastic. The other price index, which is feasible with drastic innovations, can be obtained by solving for φ_t from

$$(12) \qquad \Delta W_t = W(p_t, X_t, m_t^\delta) - W((1+\varphi_t)p_t, X_t, m_t^\delta).$$

That is, if the prices of the improved products had been $(1+\varphi_t)$ times higher than actual prices, then the implied percentage price reduction of $\varphi_t/(1+\varphi_t)$ would be equivalent to the value of innovation that took place. Hence the last price index is computed simply as $J^1 = 1/(1+\varphi_t)$.[8]

The price of each product at time t can always be written as $p_{jt} = p_t^* + \Delta_t p_{jt}^*$, where p_t^* and Δ_t are the average price and the variance of prices across the products under consideration, respectively. Trajtenberg (1990) showed that ϕ_t in (11) and φ_t in (12) can be easily calculated if the distribution of prices moves by a factor of $(1-\phi_t)$ while the variance remains unchanged over time (i.e., $\Delta_t = \Delta$). Then $p_{jt} = (1-\phi_t)p_{t-1}^* + \Delta\, p_{jt-1}^*$, and thus $\phi_t = \Delta W_t / p_{t-1}^*$. Similarly, $1+\varphi_t = (\Delta W_t + p_t^*) / p_t^*$. This assumption, however, is not valid in the case of pharmaceuticals. A stylized fact in the pharmaceutical industry is that branded prices rise over time while generic prices fall (see, for example, Currie and Park (2000)). Therefore, in the following empirical example, we will focus on the previous two innovation-adjusted price indexes, I^0 and I^1.

IV. An Empirical Example: Price Indexes for Antidepressant Drugs

IV-1. The market for antidepressant drugs

[7] The reference utility level, γ_{t-1} or γ_t, can be calculated using the total expenditure (and W) in the reference period.

The first antidepressant drug was introduced in 1958 to treat clinical depression. Since 1980, the market for antidepressant drugs has been one of the fastest growing industries. During the years 1980-1995, the Average Annual Growth Rates (AAGRs) of daily dosage units sold and revenues were 11.44% and 24.19%, respectively. For more detailed discussions of this market, refer to Berndt, Cockburn and Griliches (1996), and Currie and Park (2000). Antidepressants are categorized into four therapeutic subclasses: tricyclic antidepressants (TCAs), monoamine oxidase inhibitors (MAOIs), selective serotonin reuptake inhibitors (SSRIs), and the other antidepressant drugs ("Others"). The first of MAOIs was introduced to the market in 1959, but since then MAOIs have maintained small market shares (less than 1.5% for the years 1980-1995). In the 1960s, there had been considerable entry of TCAs. In fact, until the introduction of the SSRI subclass in 1988, TCAs had dominated the market (see figure 1). Antidepressant drugs are mainly differentiated by side effects[9] such as anticholinergic (AC),[10] drowsiness (DR), insomnia/agitation (IA), orthostatic hypotension (OH), cardiac arrythmia (CA), gasrointestinal distress (GID), weight gain (WTG), and fatal in overdose (Fatal). Other product characteristics include the daily frequency of taking the pill (Freq) and half-life (Half).[11]

The data set used in the paper contains all the antidepressant drugs for the years 1980-1995.[12] During these years, the market for antidepressants experienced 'exceptional and remarkable' innovations in terms of entry of new products (both new molecules and generics). Table 2 lists entry of new molecules and generics for the entire years in question. There have been a few exits during these years, all of them secondary brands in the TCA subclass. In 1980 and 1981, there was branded entry of the second-generation of TCAs along with the entry of a

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[8] It can be shown that $J^1 \geq J^0$.

[9] There is no strong evidence that various antidepressants have different rates of efficacy.

[10] 'AC' includes dry mouth, blurred vision, urinary hesitancy, and constipation.

[11] 'Half life' is the number of hours for the drug to leave a patient's bloodstream.

[12] We have 21 antidepressant drugs (molecules) and 35 products (branded or generic versions of a molecule) during these years. The price and quantity data are from IMS America. IMS tracks, based on actual invoices, more tan 99% of manufacturer and wholesale transactions to drugstores or their purchasing agents.

branded drug in the "Other" subclass. Beginning in 1986, generic entry in the TCA subclass became significant. This active entry of generic drugs might have been facilitated by reduced costs of generic entry due to the passage of the 1984 Waxman-Hatch Act. Most importantly, Prozac was introduced to the market in 1988, and subsequently three more drugs in the same therapeutic subclass followed suit. Prozac, the first of the SSRIs, was a breakthrough: it, as well as others in the SSRI subclass, has biologically more specific actions and thus fewer side effects.

Since the introduction of its first molecule, the market share of the SSRI subclass rose steadily, overtook the TCA subclass in 1993, and occupied 63% of the market by 1995 (see figure 1). The growth of the market for antidepressant drugs has accelerated since the introduction of the SSRI subclass in 1988. The AAGR of daily dosage units was about 5.3% from 1980 to 1987 but more than tripled to 18.3% from 1987 to 1995. Figure 2 indicates drastic increases from 1988 in the usage of antidepressant drugs to treat clinical depression although the potential size of the market has grown steadily since 1980.[13] In other words, more and more patients began to switch from the outside alternative (i.e., no treatment at all or non-drug treatment such as psychotheraphy) to antidepressant drug treatment since the introduction of the SSRI subclass. In the next subsection, we will exam the welfare gains from these innovations, which will be reflected in our innovation-adjusted price indexes.

IV-2. Price indexes

Since 1988 in which Prozac was introduced to the market, the weighted average prices, both real and nominal, also began to increase more rapidly, with an exception in 1991.[14] The AAGR of the weighted average nominal prices was 9.45% from 1980 to 1987 and 11.21% from 1987 to 1995, while the AAGR of the weighted average real prices was 4.02% from 1980 to 1987 and 7.71%

[13] The market size in a given year is calculated from the estimate of the prevalence of depression in the U.S. population multiplied by the population.

from 1987 to 1995. Except in 1981 and 1991, the weighted average real prices have continued to rise. Figure 3 illustrates the weighted average (nominal and real) prices of all the antidepressant drugs for the entire years in question. As discussed in section III, however, if the value of innovations dominates the effects of price increases, consumer surplus will rise. In the case of antidepressant drugs, innovations resulted from the entry of new products (molecules or generics) and consumers' learning about experience characteristics since the observable product characteristics did not change over time.

Based on the estimates reported in table 1, for the years 1980-1995, figure 4 illustrates the changes in consumer surplus, say $D\_W = \Delta W_t \equiv W(p_t, X_t, m_t^{\delta}) - W(p_{t-1}, X_{t-1}, m_{t-1}^{\delta})$, and the changes in consumer surplus when the experience characteristics are set to be zero, say $D\_W^* = W(p_t, X_t, 0) - W(p_{t-1}, X_{t-1}, 0)$. The difference between *D_W* and *D_W** represents the (aggregate) contribution of experience characteristics to the increase of consumer surplus.[15] Over the entire years in question, the average increase of consumer surplus, *D_W*, due to the aggregate learning effects was 11.17%. Figure 4 indicates that big welfare gains from consumer learning effects were followed by the active generic entry (facilitated by the 1984 Waxman-Hatch Act) in 1986, and the entry of Prozac in 1988. For 1989 – 1991, there was a setback following these huge learning effects. However, the aggregate learning effects account for 17.3% of average increase in consumer surplus for 1987 – 1993. The pattern of learning effects over time illustrated in figure 4 implies that consumers quickly learn experience characteristics. Table 4 quantifies the effects of consumers' learning about experience characteristics in the AAGRs of the price indexes. For the entire period, learning effects contributed to the decrease in our focal price index I^1 by 0.43%, about 4.48% of the average annual reduction reported in table 3. Especially from 1987 to 1993, learning effects contributed to the decrease in focal price index I^1 by 1.14%,

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[14] Real prices mean the prices deflated by the CPI to convert into 1980 dollars.

[15] With positive consumer learning effects, producers may set prices higher (due to higher mean levels of utility for the products) or lower (in order to build up more consumption experiences).

roughly 10.33% of the average annual reduction reported in table 3. The contribution of learning effects becomes more significant if we base it on the price index J^1 (see table 4).

Figure 4 indicates two big jumps of *D_W* in 1987-1988 and 1990-1991. The big jump in 1987-1988 demonstrates the impact of the introduction of Prozac, proving that it was a breakthrough in the antidepressant drug industry. The jump in 1990-1991 was due primarily to the decrease in weighted average real price. Except in 1991, as indicated in figure 2, the weighted average prices increased rapidly from 1988. This is mainly because the SSRIs were priced substantially higher than others,[16] but their market share continued to rise (except in 1991). Hence, the sharp drop of the weighted average real prices in 1991 reflects aggressive price cuts of the other products (especially TCAs) in response to the surge of Prozac, which resulted in the drop of the market share of Prozac in 1991 (see figure 1). In that sense, the jump in 1990-1991 reflects another face of the drastic innovation caused by the introduction of the breakthrough drug. Furthermore, the positive values of *D_W* in 1991-1995 reflect the innovations resulting from subsequent entry of new molecules in the SSRI subclass as shown in table 2.

The high values of *D_W* for 1980-1982 in figure 4 reflect the entry of the second-generation branded drugs in the TCA subclass (and the "Other" subclass). The decline of weighted average real prices in 1981 may imply strategic price cuts of the existing antidepressant drugs in response to the introduction of the second-generation TCAs in 1980 and 1981. The big surge of *D_W* in 1985-1987 illustrates the value of innovations resulting from a flurry of generic entries in the TCA subclass, which might have been facilitated by the 1984 Waxman-Hatch Act. For 1982-1985 and for 1988-1990, *D_W* had negative values. In other words, the effects of price increases dominated the positive values of innovations. During these years, there was no significant entry of new products.

[16] In 1988, the price of Prozac was about five times as expensive as the average price of TCA branded drugs.

Based on the estimation results in table 1, figure 5 illustrates the four real price indexes defined in section III. Figure 6 calculates the (nominal) price indexes I^1 and J^1 in the sense that increases in the price levels of the outside alternative are taken into account. Figure 5 and figure 6 clearly demonstrate that these calculated price indexes truthfully reflect the changes in consumer surplus reported in figure 4. The nominal indexes have higher values than the real indexes, but the movements of the two are parallel. Figure 6 shows that our focal index I^1 has a more fluctuation over time than J^1. The four real price indexes show decreases in the innovation-adjusted price for the entire years in question, except in the years 1982-1985 and 1988-1990 when increases of social surplus are negative. The nominal indexes have increased in 1981-1982 in addition to these years. Overall, however, the values of innovations resulting from a series of entries of new products and learning about experience characteristics have been dominant. Especially in 1987-1988 and 1990-1991, the price index I^0 has negative signs, which imply the occurrence of drastic innovations in 1988 and 1991.

We now proceed to compare our price indexes reported in figure 6 with those calculated in the previous studies. In June 1980, the PPI program at the BLS began publishing a monthly price index for "psychotherapeutics" consisting of tranquilizers and antidepressants ("Cycle A" sample). In December of 1987, the BLS created a separate antidepressants category ("Cycle B" sample) and updated its sample in December of 1993 ("Cycle C" sample). The PPI published by the BLS is calculated by a modified Laspeyres formula. However, the BLS PPI for antidepressants may have had an upward bias since the BLS had implicitly treated generic versions of a drug as entirely distinct and non-substitutable products.[17] The FDA, on the other hand, has argued the other extreme: "a pill, is a pill, is a pill." In this case, the relevant price for a molecule will be the weighted average price of all generic drugs and the branded drug within the molecule. Beginning in May 1996, the BLS adopted a new procedure, which treats generics and

their branded antecedents as perfect substitutes and calculates the Laspeyres index with fixed branded weight split into a 64.2% generic component and a 35.8% branded component. Emphasizing the importance of new products, Berndt, Cockburn and Griliches (1996) calculated a Paasche price index for antidepressants based on the Griliches-Cockburn adjusted Paasche Diffusion (GCPD) method developed in Griliches and Cockburn (1994). They predicted the reservation prices of new molecules based on estimates of hedonic price indexes, while they calculated the base-month's reservation price of a generic drug as the average six-month-later price of the generic drug and its branded antecedent.

Table 3 shows the AAGRs for several different alternative price index calculations. Because of drastic innovations in 1988 and 1991 and the reasons discussed in section III, we use I^1 as our focal index. For the entire years in question, the AAGR of I^1 is –9.52% (the AAGR of J^1 is –6.65%).[18] In other words, there has been roughly a 9.5% annual decline of innovation-adjusted average prices of antidepressant drugs. During the same time period, the AAGR of weighted average nominal prices is 10.38%. These numbers indicate that despite substantial increases in prices, there has been an 'exceptional and remarkable' series of innovations in the market for antidepressant drugs during the years in question. Recall that a huge number of people under clinical depression, who might have had no treatment at all or chosen expensive non-drug treatment such as psychotheraphy, turned for antidepressant drugs since the introduction of the SSRI subclass in 1988 (see figure 2). The AAGR of I^1 for this market, -9.52%, is not a surprising figure, compared to those of price indexes for PCs and CT scanners. The AAGR of hedonic price indexes was –30% in the U.S. PC market over the 1988-1992 time period (see Berndt, Griliches and Rappaport (1995)), and the AAGR of the price indexes J^1 for CT scanners reported in Trajtenberg (1990) was –55.87% over the 1974-1982 time period.

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[17] In addition, the BLS PPI had a problem caused by the employed weights. For example, Cycle C sample excludes Prozac, the largest selling antidepressant, since Prozac is manufactured in Puerto Rico. Refer to Berndt, Cockburn and Griliches (1996) for a detailed discussion about the BLS PPI.

All the other indexes of the previous studies, however, reported positive values of AAGRs for the market for antidepressants: 2.95% of the FDA average price, 3.71% of the New BLS procedure, and 4.33% of the GCPD.[19] Moreover, these three indexes, along with the BLS index, have higher values of AAGRs in period II (1987 to 1993) than in period III (1993 to 1995). As discussed above, the most substantial and remarkable innovations occurred in period II. As shown in figure 4, there are two big jumps of the increase of consumer surplus in 1987-1988 and 1991-1992, resulting from the introduction of Prozac and the drastic price cuts of the other products in response to the surge of Prozac. Our innovation-adjusted indexes I^1 and J^1 show faster declines of the growth rates in period II than in period III (although there were sharp increases of I^1 and J^1 in 1988-1990). The other three price indexes as well as the BLS index fail to capture these substantial and remarkable innovations caused by the introduction of the breakthrough subclass, SSRI. The prices of SSRIs were substantially higher than the other antidepressants, and steadily increased over this time period. These previous indexes overstated the increases in prices, not truthfully reflecting the exceptional and remarkable innovations in period II. Note also that our innovation-adjusted price indexes have substantially lower values in period I, compared to the previous three indexes. In period I, the price increases were slower than in periods II and III, but consumers substantially benefited from the introduction of the second-generation of TCAs and a flurry of generic entries facilitated by 1984 Waxman-Hatch act.

Our model presented in section II does not consider a moral hazard problem. As discussed by Keeler (1996), fee-for-service health insurance may exaggerate a consumer's apparent marginal willingness to pay for newer or more expensive drugs than managed care such as Health Maintenance Organizations (HMO). Managed care has grown from 1980 to the present. Hence the moral hazard problem was likely to be more important in the early 1980s. In the case

[18] We calculate the AAGR from year 0 to year n, say g, by solving: $(1+g)^n = I_{01}\, I_{12} \ldots I_{n-1n}$, where I_{ii+1} is the price index from year i to year i+1.

of antidepressant drugs, however, the moral hazard problem has not been apparent. As shown in figure 2 of Berndt, Cockburn and Griliches (1996), the share of branded drugs had steadily declined until the year 1985, and then picked up again in the year 1988. This means that the rise of the share of branded drugs occurred as HMO became more widely adopted. This rise was mainly due to the introduction of new breakthrough molecules, SSRIs, from the year 1988, which induced the most important innovations and the substantial declines of innovation-adjusted price indexes. In general, as discussed in Keeler (1996), there is little evidence as to whether this moral hazard problem is significant in the purchase of pharmaceuticals.[20]

V. Concluding Remarks

This paper has proposed innovation-adjusted price indexes for pharmaceuticals, based on the characteristics approach to demand functions and the Bayesian learning process of experience characteristics. This structural approach not only resolves quality adjustment of new molecules, but also avoids arbitrary assumptions about the link-in of generic drugs to the originator branded drug. In this paper, the link-in problem has been treated in a context of informational product differentiation between generic drugs and the originator branded drug. The suggested price indexes have been applied to the data for antidepressant drugs during the years 1980-1995. Our calculated innovation-adjusted indexes truthfully reflect exceptional and remarkable innovations in the market for antidepressants during these years: the AAGR of the focal price index is –9.5%. We have also found that the key source of innovations was a series of entries of new products, but the effects of learning about experience characteristics were significant as well. The introduction of Prozac is captured as a drastic innovation both in 1988 when it was introduced into the market

[19] Note that these three indexes are calculated using monthly data.
[20] A steady rise of the share of generic drugs in the first half of 1980s can also be explained by the effects of learning about experience characteristics instead of the implications of the moral hazard and the expansion of HMOs in 1980s.

and in 1991 when the surge of Prozac was met by drastic price cuts of the other antidepressants. The results we have obtained in this paper suggest that all the other existing indexes discussed in Berndt, Cockburn and Griliches (1996) seriously understate the value of innovations and thus substantially overstate the rate of inflation of antidepressant drugs in this rapidly growing market with the entry of innovative new products. Considering the importance of price indexes for pharmaceuticals in the health care reform, we invite more applications of our innovation-adjusted price indexes to other pharmaceuticals.

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Table 1: Results of Regression

variable	estimate	st. error	t ratio
constant	0.235	1.726	0.14
price	-0.324	0.294	-1.10
generic	0.427	0.187	2.28
Within-group Correlation			
sigma_tca	0.063	0.037	1.71
sigma_maoi	0.535	0.271	1.98
sigma_ssri	0.495	0.265	1.87
sigma_other	0.356	0.291	1.22
sigma_molecule	0.262	0.116	2.25
Product Characteristics			
Insomnia/Agitation	-0.826	0.303	-2.72
Drowsiness	-0.426	0.331	-1.29
Anticholinergic	0.466	0.526	0.89
Frequency	-0.263	0.298	-0.88
Fatal	0.305	0.483	0.63
Gastrointenstinal	0.110	0.136	0.81
Weight Gain	-0.157	0.345	-0.45
Cardiac	0.186	0.401	0.46
Orthostatic Hypotension	-0.186	0.153	-1.22
Half-life	0.004	0.006	0.68
Consumption Experience			
SSRI	0.257	1.114	0.23
all the others	0.673	0.575	1.17
Prior Covariance Martix			
Var[delta]	0.576	1.414	0.41
Var[A_detail]	0.270	1.550	0.17
Var[A_journal]	1.229	7.316	0.17
Cov[delta, A_detail]	0.117	0.343	0.34
Cov[delta, A_journal]	0.329	0.719	0.46
Cov[A_detail, A_journal]	0.604	0.011	53.64

Table 2: Entry in the Antidepressant Drug Market, 1980 - 1995

year	molecules
1980	amoxapine (branded version, TCA)
1981	maprotiline (branded version; TCA); trazodone (branded version; Others)
1982	
1983	
1984	
1985	
1986	doxepin (generic version; TCA); trazodone (generic version, Others)
1987	desipramine (generic version; TCA)
1988	fluoxetine (branded version, SSRI); maprotiline (generic version, TCA); trimipramine (generic version, TCA)
1989	bupropion (branded version; Others); amoxapine (generic version, TCA)
1990	clomipramine (branded version; TCA)
1991	
1992	sertraline (branded version, SSRI); nortriptyline (generic version, TCA); nortriptyline (generic version, TCA)
1993	paroxetine (branded version, SSRI)
1994	fluvoxamine (branded version, SSRI); venlafaxine (branded version, Others)
1995	nefazodone (branded version, SSRI)

Table 3: Average Annual Growth Rates of Price Indexes

Procedure	Entire period 1980-1995	Period I 1980-1987	Period II 1987-1993	Period III 1993-1995
weighted average price	10.38	9.45	12.16	8.41
I_1*	-9.52	-9.9	-11.08	-3.29
J_1*	-6.65	-5.85	-8.95	-2.39
FDA average price**	2.95	5.71	1.33	1.1
New BLS**	3.71	7.41	2.49	0.42
GCPD**	4.33	7.08	3.99	0.52
BLS index**	NA	NA	10.4	4.27

* For the definitions, refer to the text.

** source: Berndt, Cockburn and Griliches (1996). For these four indexes, the entire period covers from 1980:1 to 1996:2, period I from 1981:12-1987:12, period II from 1987:12 to 1993:12, period III from 1993:12 to 1996:2.

Table 4: The Effects of Experience Characteristics

	% decrease in AAGR due to experience characteristics	
	I_1	J_1
Entire period, 1980-1995	4.48	9.87
Period I, 1981-1987	-0.28	-0.95
Period II, 1987-1993	10.33	19.33
Period III, 1993-1995	-5.98	-7.41

Figure 1

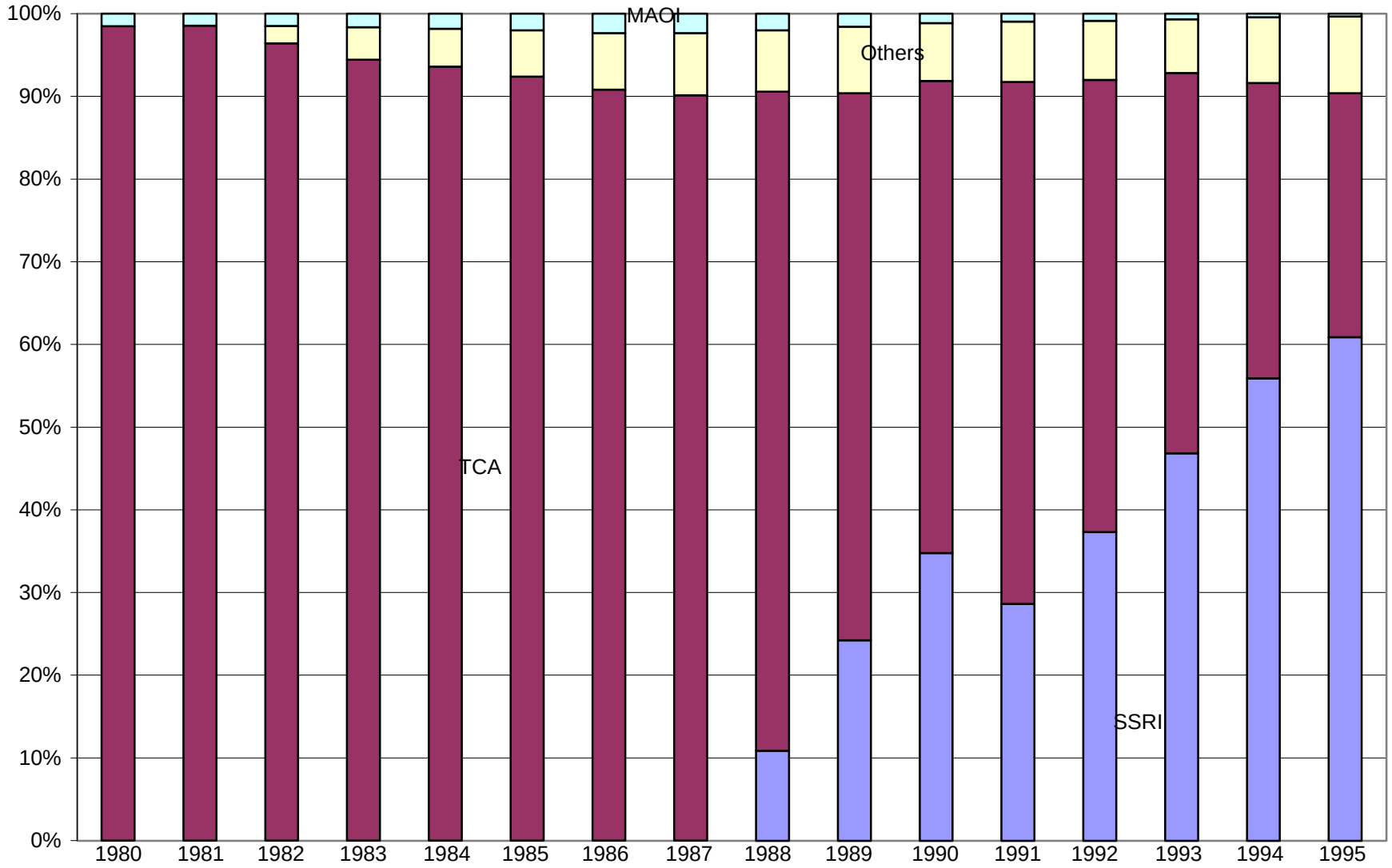

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
MAOI
Others
TCA
SSRI
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

Figure 2

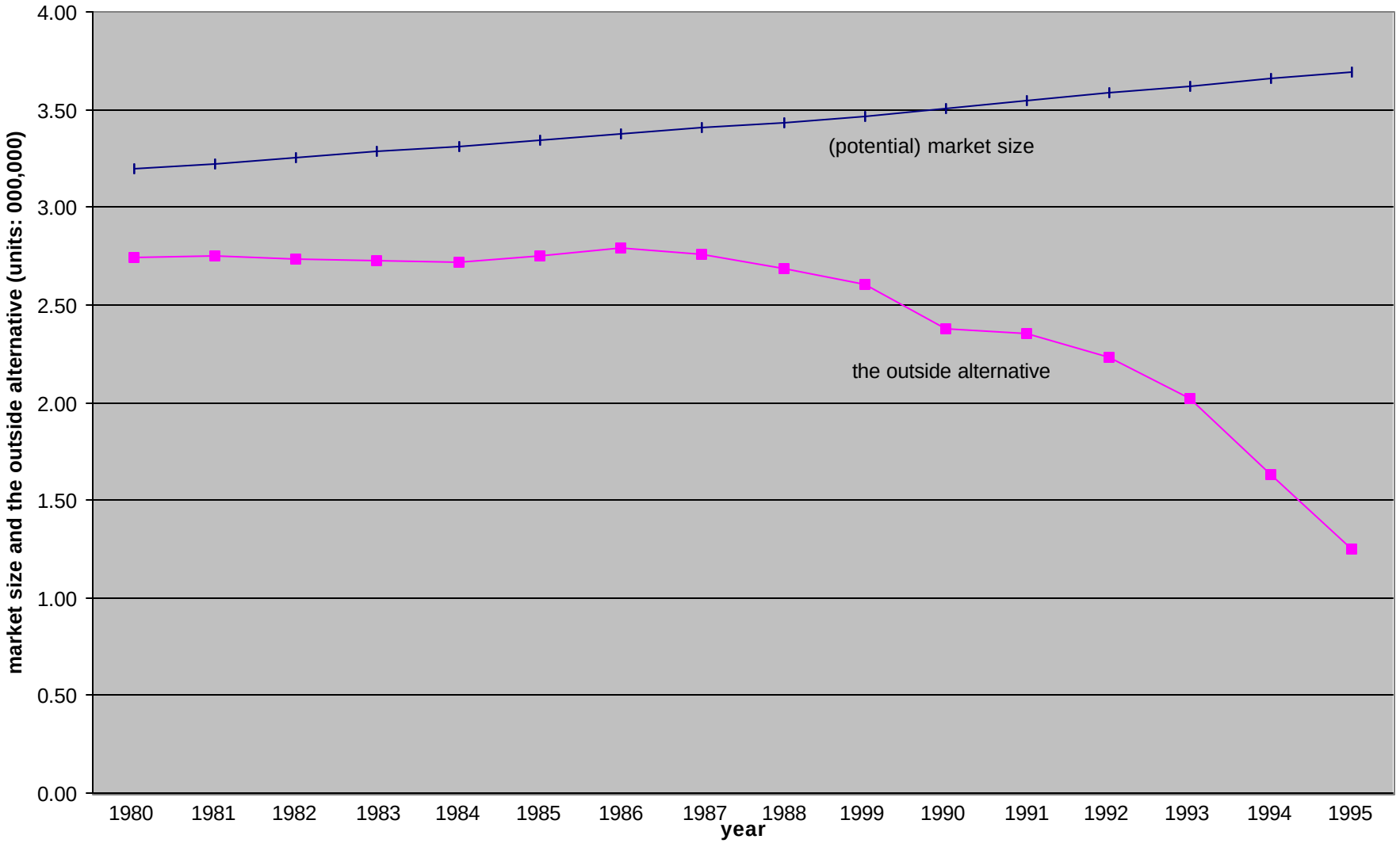

4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
market size and the outside alternative (units: 000,000)
(potential) market size
the outside alternative
1980
1981
1982
1983
1984
1985
1986
1987
1988
1999
1990
1991
1992
1993
1994
1995
year

Figure 3

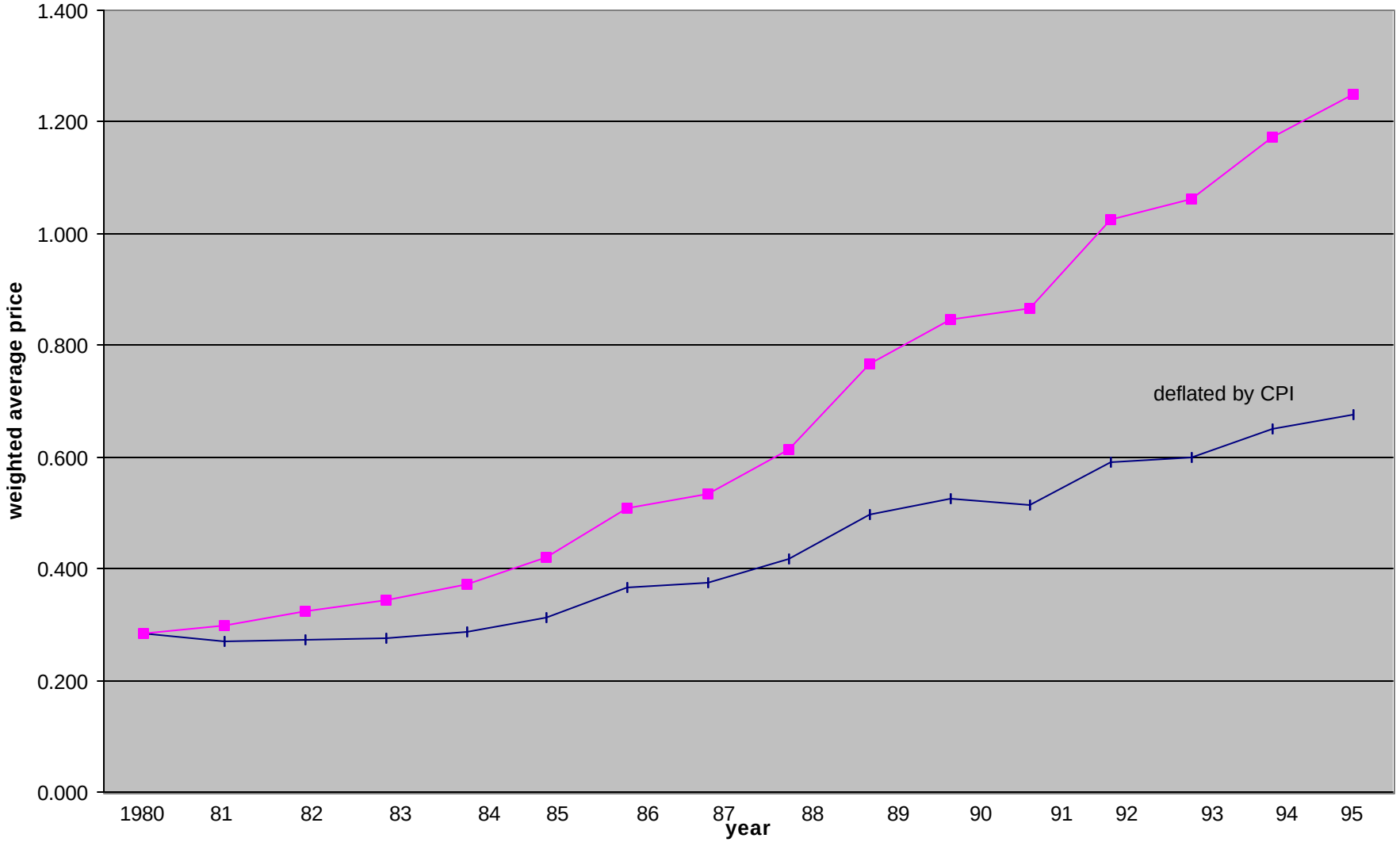
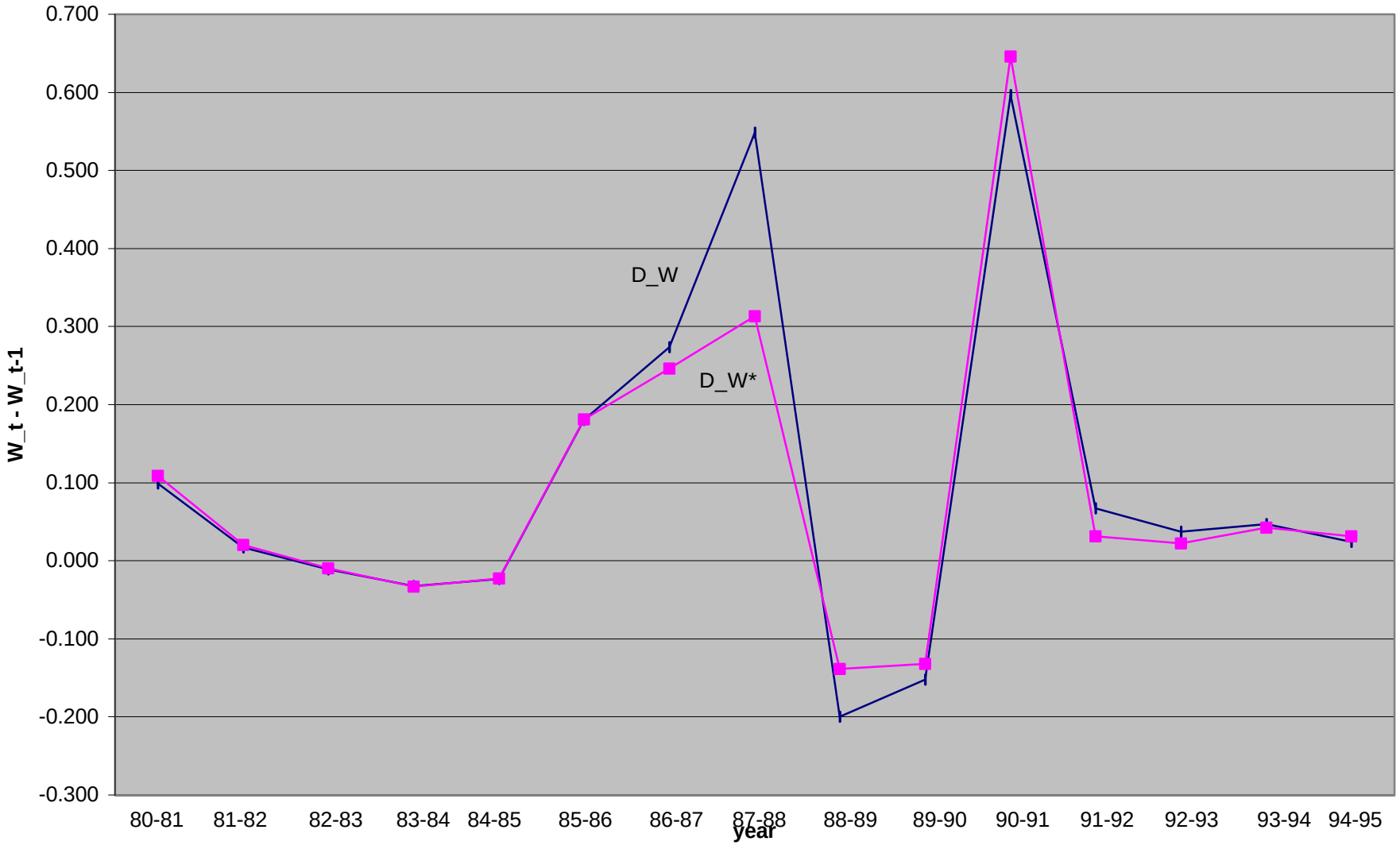

1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
weighted average price
deflated by CPI
1980
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
year

Figure 4


0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
W_t - W_t-1
D_W
D_W*
80-81
81-82
82-83
83-84
84-85
85-86
86-87
87-88
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89-90
90-91
91-92
92-93
93-94
94-95
year

Figure 5

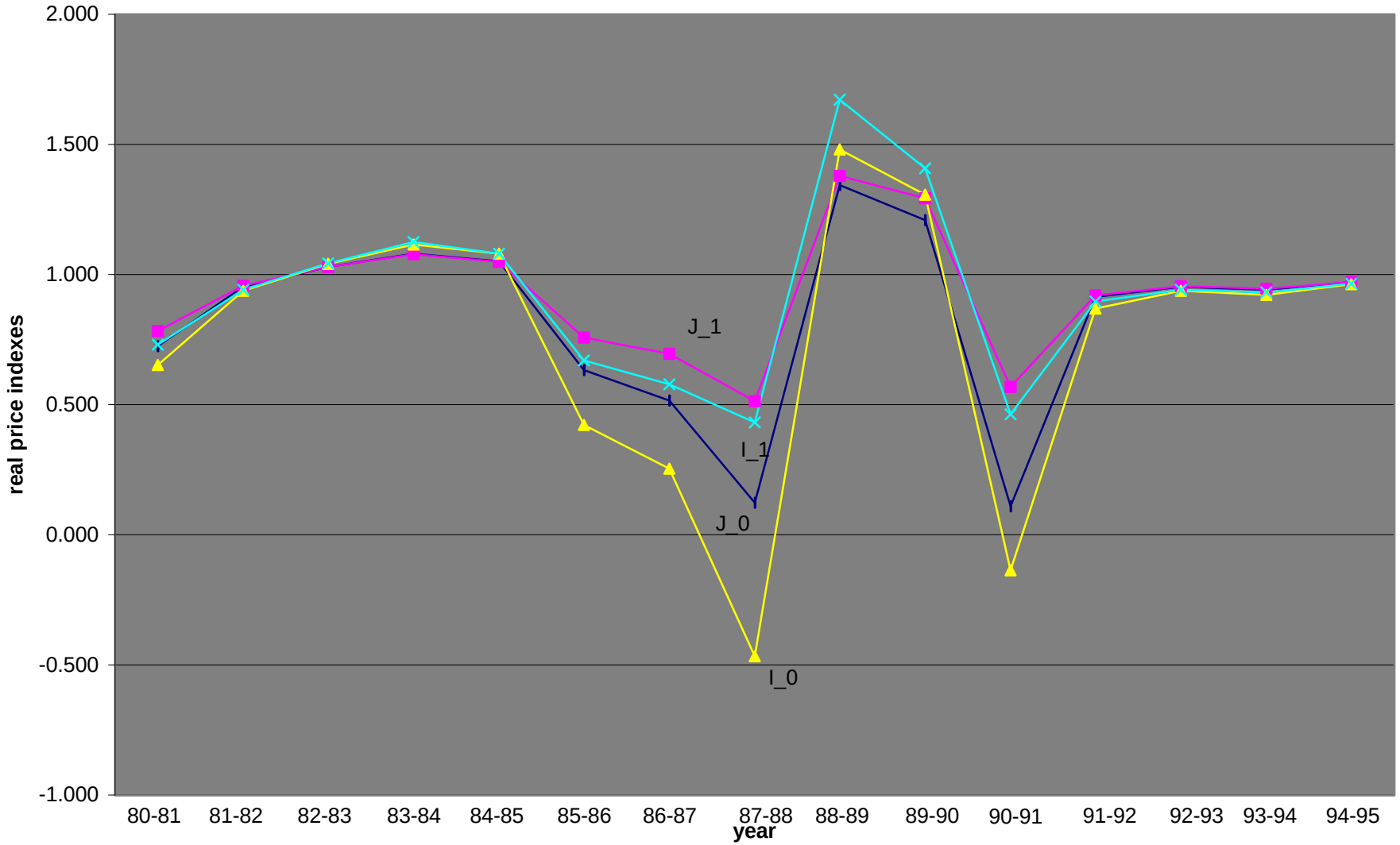
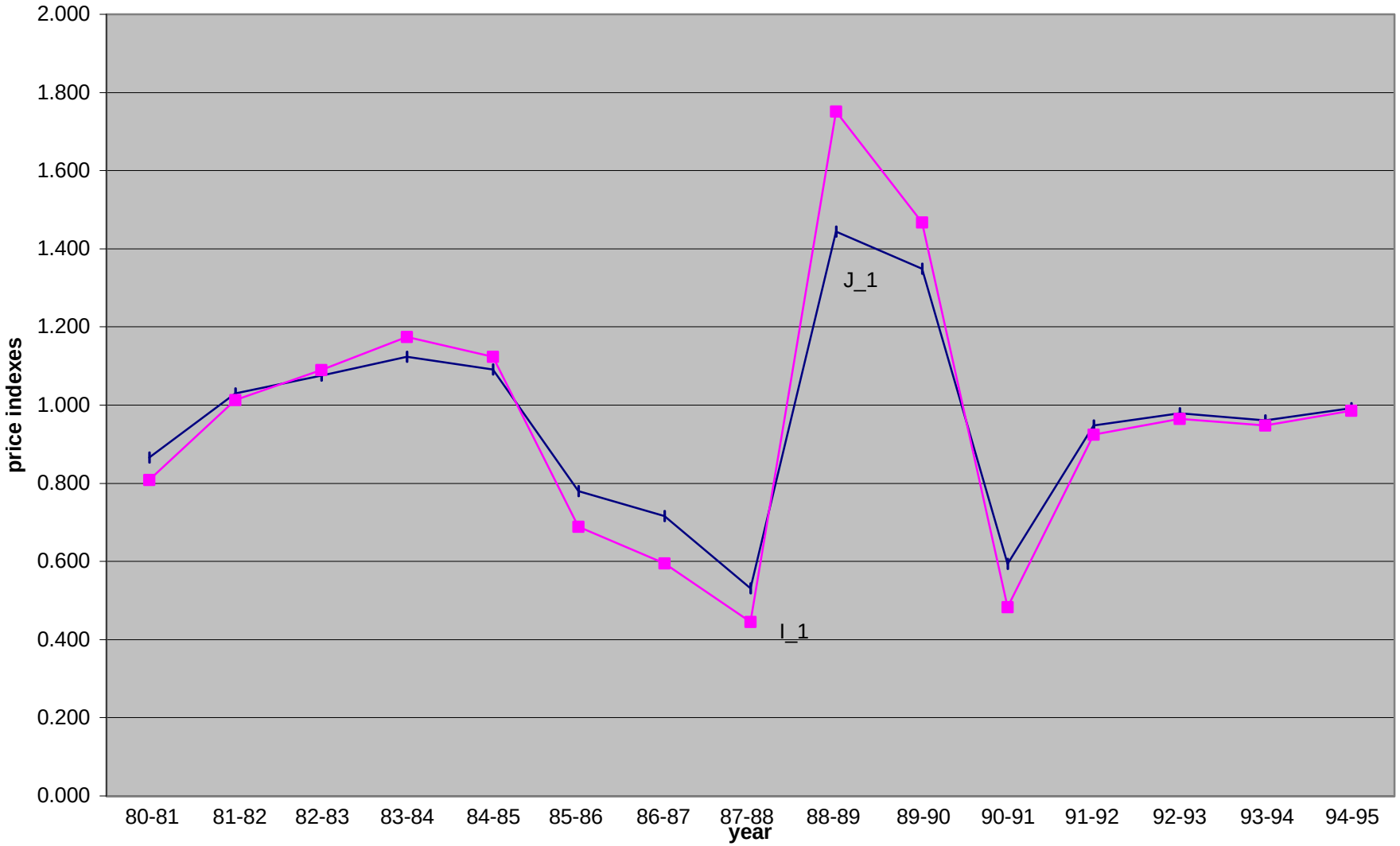

2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
real price indexes
J_1
I_1
J_0
I_0
80-81
81-82
82-83
83-84
84-85
85-86
86-87
87-88
88-89
89-90
90-91
91-92
92-93
93-94
94-95
year

Figure 6


2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
price indexes
J_1
I_1
80-81
81-82
82-83
83-84
84-85
85-86
86-87
87-88
88-89
89-90
90-91
91-92
92-93
93-94
94-95
year